Lithium-Ion Batteries for Aerospace Applications

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Como, Italy

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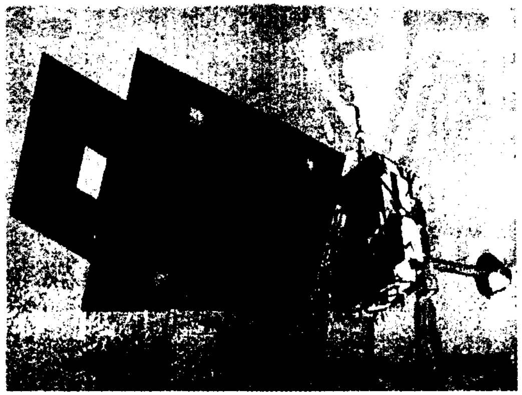
Outline

- **Potential NASA and AF Applications**
- **Battery Requirements**
- **Interagency Li-Ion Battery Program**
- **Technology Assessment**
- **Summary and Conclusions**

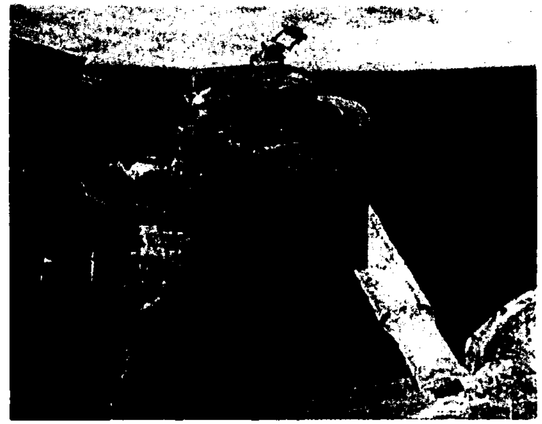
Potential NASA Applications

Planetary Landers

GEO Spacecraft

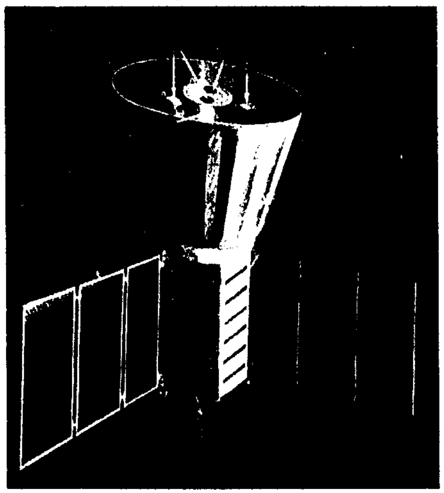


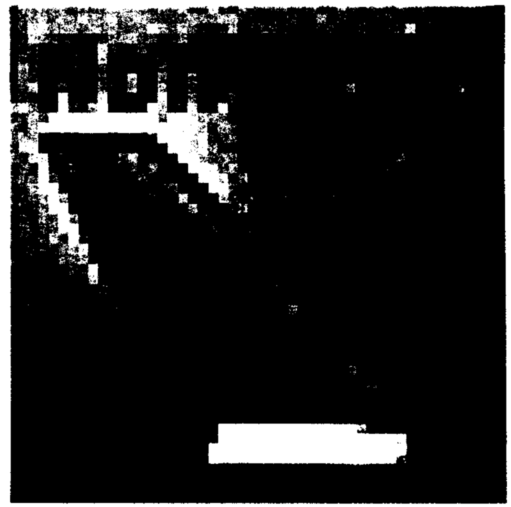
Astronaut Equipment



Europa Orbitter

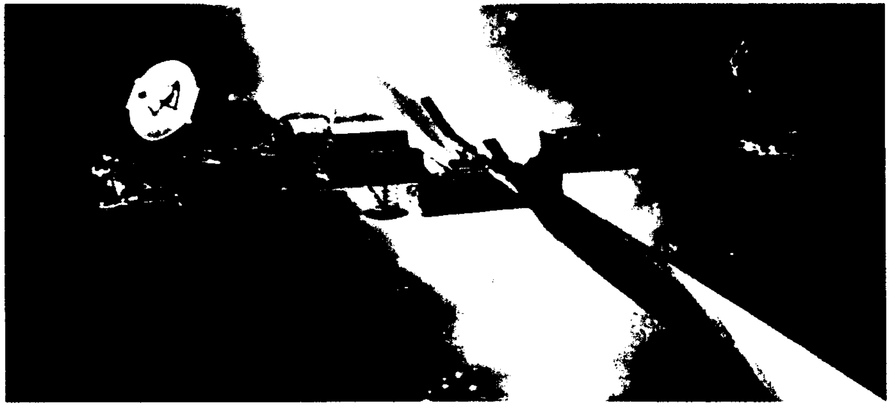
LEO Spacecraft



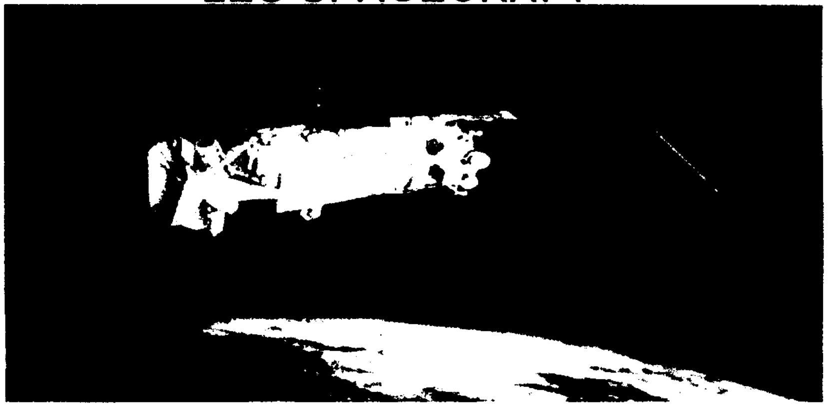


Potential Air Force Applications

GEO SPACECRAFT



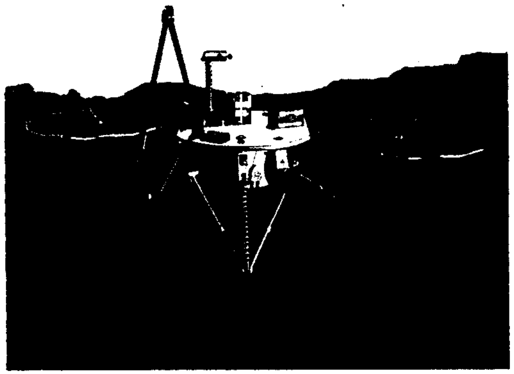
LEO SPACECRAFT



AIRCRAFT

UAVS

Mars 2003 Lander



Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

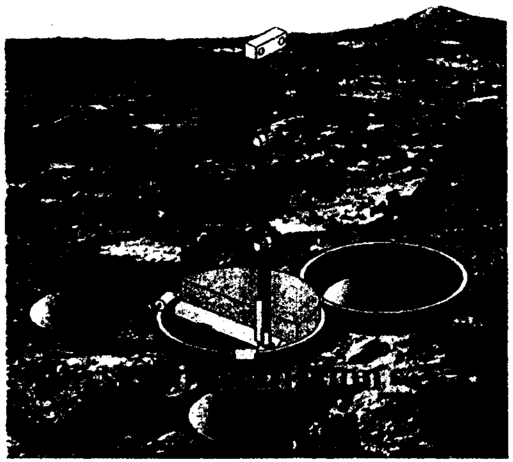
Battery Requirements

- Voltage: 24-32
- Capacity: 68 Ah
- Operating Temp.:-20-40 C
- Cycle Life: 300
- Calendar Life: Three years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Battery Operation after Two years Active storage.
- Low Temperature Performance

Mars Scout Missions



Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives

- Lander robustness
- Evaluate landing sites

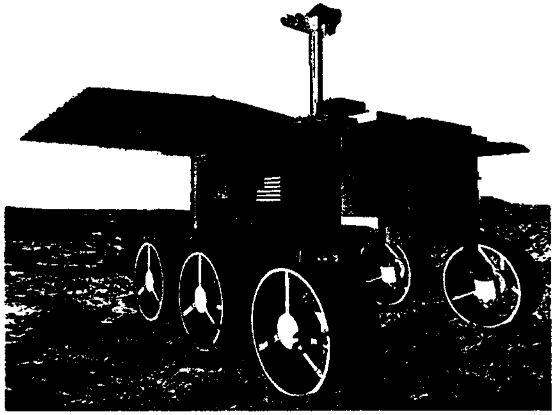
Battery Requirements

- Voltage: 24-32 V
- Capacity: 6-8 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: Five years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh

Technology Challenges

- Battery Operation after Two years Active storage
- Low Temperature Performance

Mars 2005 Lander/Rover



Launch Date: April 2005
Flight Time: Nine Months

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

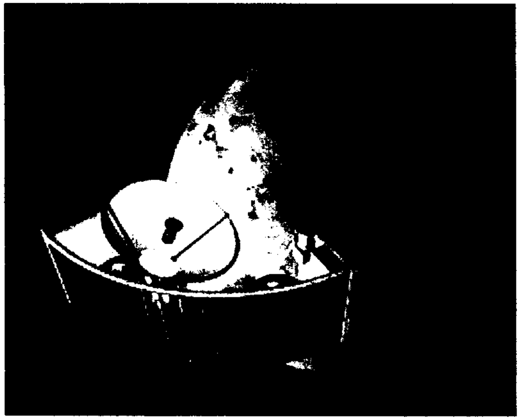
Battery Requirements

- Voltage: 24-32
- Capacity: 100 Ah
- Operating Temp.:-20-40 C
- Cycle Life: > 300
- Calendar Life: Three years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Battery Operation after Two years Active storage
- Low Temperature Performance

Mars Microsats



Launch Date: 2003
Flight Time: Nine Months

Mission Objectives

- Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth;
- Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.

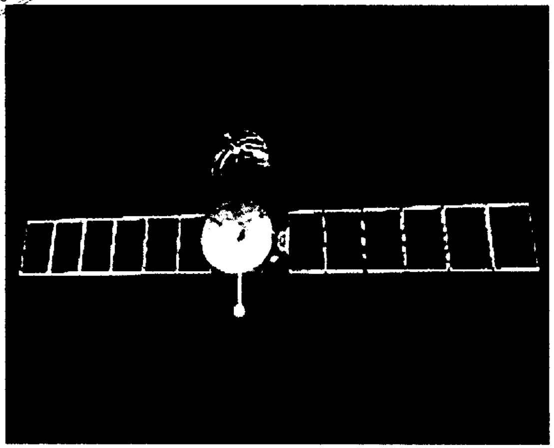
Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: Five years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Long Cycle Life

Mars Sats



Launch Date: Jan 200X
Flight Time: Nine Months

Mission Objectives

- Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth.
- Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.

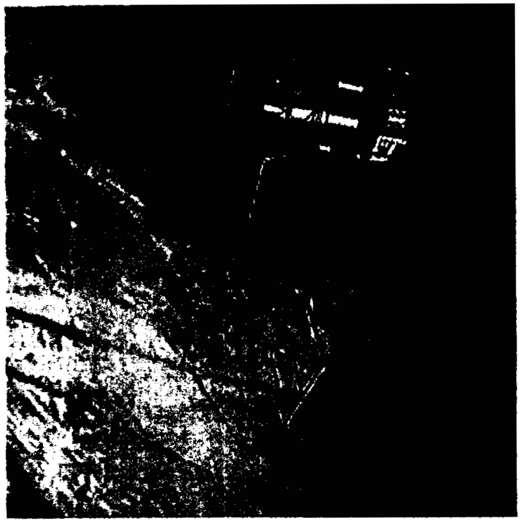
Battery Requirements

- Voltage: 24-32
- Capacity: 20 -35 Ah
- Cycle Life: > 30 K, at 20-30% DoD
- Calendar Life: 7-9 years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Long Cycle Life

Europa Orbiter



Launch Date: January 2006
Flight Time: 3-4 Years

Mission Objectives

- Determine the presence or absence of a subsurface ocean
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: < 400
- Calendar Life: 6-8 Years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Long Calendar Life
- Radiation Tolerance

Solar Probe

Launch Date: 2007
Flight Time: 3.8 - 1st Perihelion
4.5 - 2nd Perihelion

Mission Objectives

- Determine the acceleration processes and find the source regions of the fast and slow solar wind at maximum and minimum solar activity.
- Locate the source and trace the flow of energy that heats the corona;
- Construct the 3-d density configuration from pole to pole, and determine the subsurface flow pattern, the structure of the polar magnetic field and its relationship with the overlying corona.

Battery Requirements

- Voltage: 24-32 V
- Capacity: 6-8 Ah
- Cycle Life: < 400
- Calendar Life: 5-7 Years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Long Calendar Life

Summary of Power System Characteristics of Missions Under Study

	Power Source	Max Power Watt	Energy Storage	Wh / batt. Mass	Power Electronics Technology
Neptune Orbiter II	UltraFlex (Adv. Si @19%)	15,753 W	1°Li-$SOCl_2$	173	MCM
Launch (2006)	70 m^2			0.7 kg	
	137 kg				
Io Volcanic Obs	AMTEC	150 W	Li-Ion	210	MCM
	14.5 kg			2.6 kg	
TPF -(Terrestrial Planet Finder)	UltraFlex (GaA[illegible]	2074 W	[illegible]Ion	840	VME
Launch ([illegible])	[illegible]			10.5 kg	
Mercury Orbiter	Fixed GaAs Solar Array	4782 W	Li-Ion	720	MCM
Launch (2005)	25.6 m^2			9 kg	
	73.5 kg				
Jupiter [illegible] Orbit[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	MCM
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Interagency Lithium Ion Battery Program-Summary

- Initiated in FY 1998 to meet the advanced battery needs of future NASA/DOD Missions
- Program leverages capabilities, facilities and resources of both NASA and DOD
- AFRL, NASA and ARL are key players
- Program coordinated with other Government Agencies (USABC, DOE, CIA, Navy) and Aerospace Primes (LMA TRW and Boeing)
- Performance Period: 1998-2004

Interagency Li-Ion Battery Program

Objectives

- Develop aerospace quality, high energy density and long life lithium-ion cells and batteries.
- Establish U.S. production sources.
- Demonstrate technology readiness
  - Rovers and Landers by 2000
  - Aviation / UAV's by 2001
  - DOD terrestrial applications by 2001
  - GEO missions by 2002
  - LEO missions by 2004

Interagency Li-Ion Battery Program
Performance Targets

	LANDERS	ROVERS	GEO ORBITER	LEO/PLA> ORBITER	AIRCRAFT	UAV
CAPACITY, Ah	30	8	10, 20, 35	10, 20, 35	5-20	100-200
VOLATAGE (v)	28	28	28-100	28	28-270	28-100
DISCH. RATE	C/5-C	C/5-C/2	C/2	C/2-C	C	C/5-C
CYCLE LIFE @DOD (%)	>500 >60%	>500 >60%	>2000 >75%	>30,000 >30%	>1000 >50%	>1000 >50%
OPERATING TEMP, ^{o}C	-40 to 40	-40 to 40	-5 to 30	-5 to 30	-40 to 65	-40 to 65
Calendar Life	3	3	>10	>5	>5	>5
SP. ENERGY (Wh/Kg)*	> 100	> 100	> 100	> 100	> 100	100
ENRGY DENSITY (Wh/l)*	120-160	120-160	120-160	120-160	120-160	120-160

Based on 100%DOD at BOL

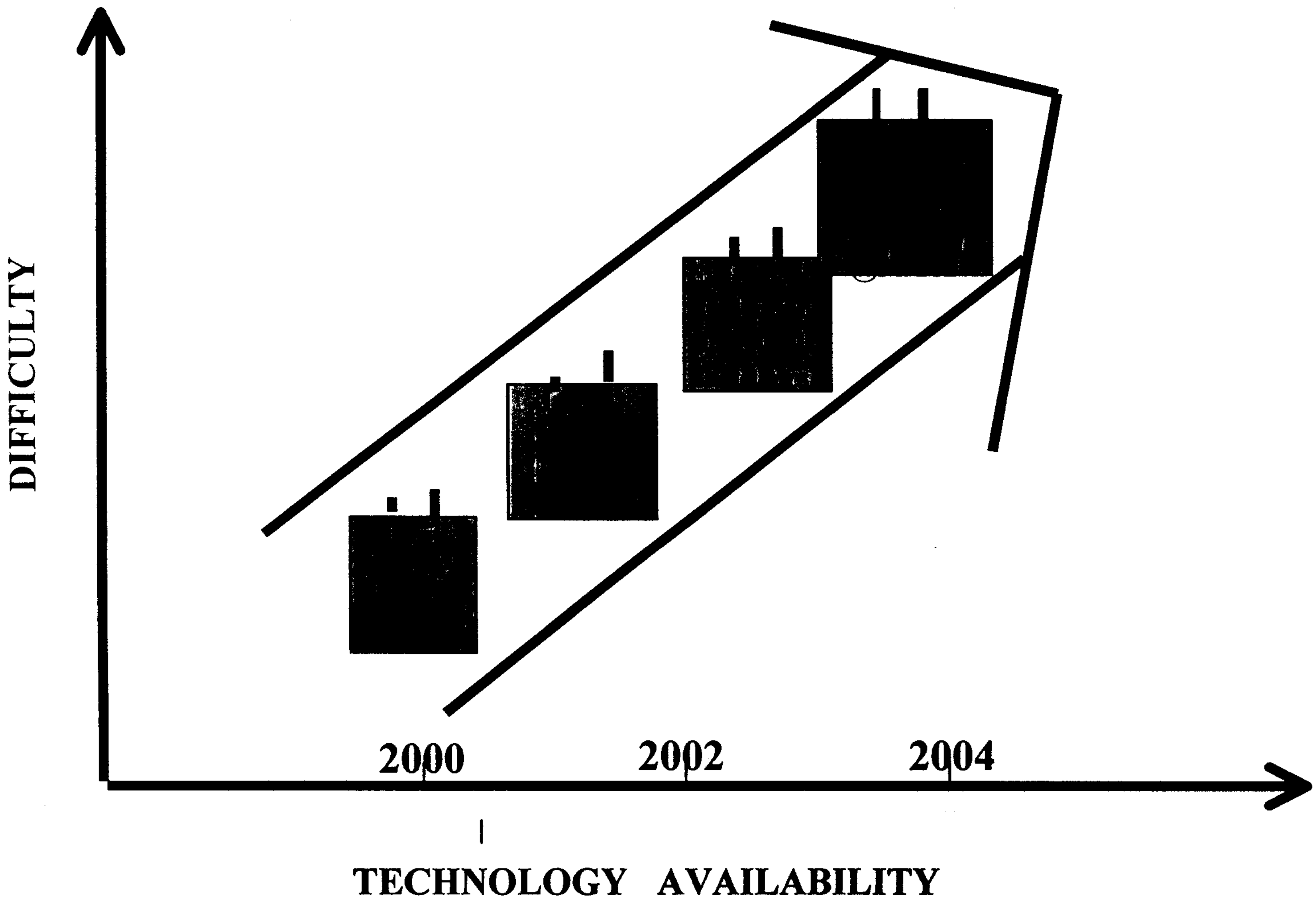
Unique Requirements of NASA/DOD Missions

- **Large capacity cells**
- **Improved low temperature performance**
- **Long cycle life**
- **Long calendar life**
- **Radiation tolerance**
- **Improved safety and reliability**

Technology Approach

- **Develop advanced materials, components to improve cell performance**
- **Optimize cell design to improve cell performance.**
- **Establish manufacturing processes and facilities to produce cells and batteries with predictable performance**
- **Develop large size lithium ion cells (7, 20, 50 and 200 Ah sizes)**
- **Demonstrate technology readiness for various NASA and DOD missions.**
  - **Develop prototype batteries**
  - **14V, 28V , 100 V, and 270 V configurations**
- **Develop smart battery management electronics**
- **Establish performance and safety database**

Technology Demonstration Milestones



Program Status

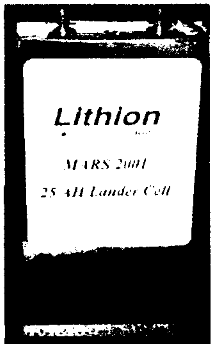
LI-ION PROGRAM ACCOMPLISHMENTS

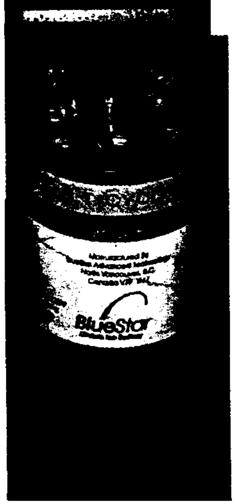
- **Awarded contracts to 4 manufacturers**
- **Transferred NASA/DOD technology to manufacturers**
- **Scaled up Li-Ion Cell technology from 1 Ah to 6-50 Ah cell sizes**
- **Developed Li-Ion cells capable of operating at low temperatures (> -20°C)**
- **Demonstrated > 1000 cycles at 100% DOD**
- **Demonstrated more than 6000 LEO cycles with first generation cells**
- **Demonstrated cell / battery technology readiness for Mars 01 Lander**
- **Lockheed-Martin has Selected Yardney for Mars 01/03 Mission**

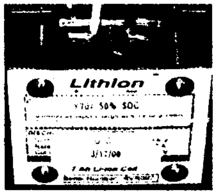
Li-Ion Program Accomplishments
Contracts with 4 Manufacturers

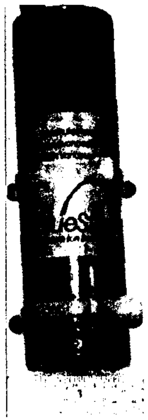
- YARDNEY TECHNICAL PRODUCTS INC.
  - **Develop Batteries for Landers, Rovers, GEO & LEO, and Aircraft.**
  - **Develop Charge Control Methodology and Electronics.**
- EAGLE-PICHER INDUSTRIES
  - **Develop Cells for Aircraft, GEO, LEO**
  - **Options for Batteries and Charger**
- BLUESTAR BATTERY SYSTEMS INC.
  - **Develop Lander/Rover Cells and Batteries,**
  - **Options for GEO and LEO**
- SAFT(Cancelled)
  - **Develop Lander/Rover Cells and Batteries**
  - **Options for GEO and LEO**

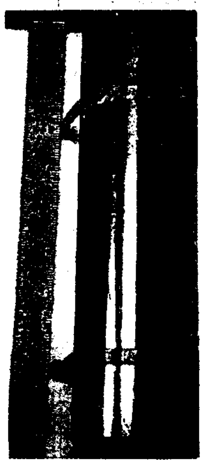
Interagency Li-Ion Battery Program
Accomplishments - Lander and Rover Cells Dev.









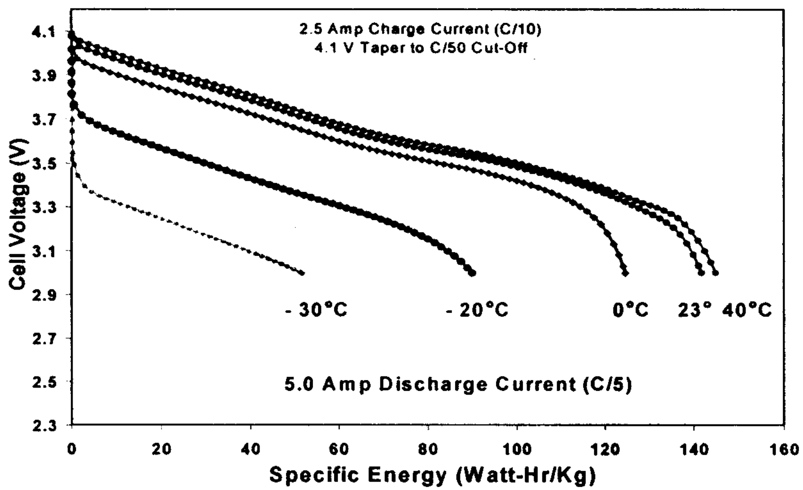


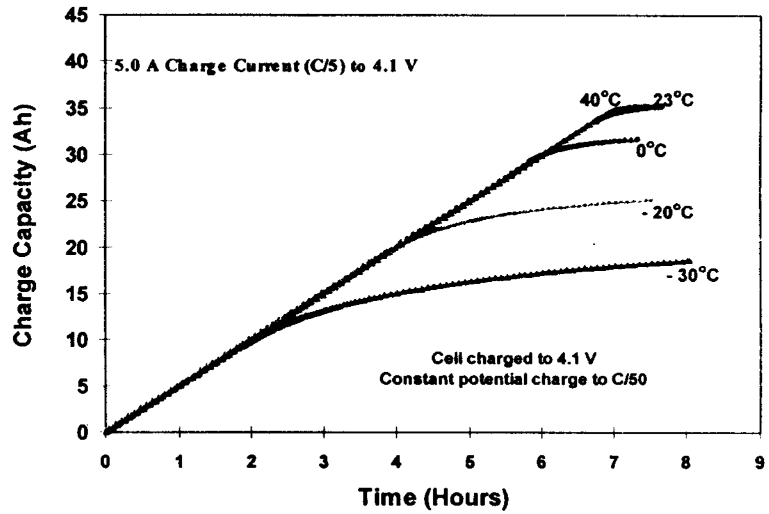
- Yardney
  - **Baseline 5 Ah Cells**
  - **1st Generation 20 Ah Cells for Mars Lander**
  - **2nd Generation 20/25 Ah cells for Mars Lander**
  - **1st Generation 8Ah Cells for Rover**
  - **MSP 01 25/35 Cells**
- BlueStar
  - **Baseline 20 Ah Cells**
  - **1st Generation 25 Ah Cells for Mars Lander**
  - **2nd Generation 25/35 Ah Cells for Mars Lander**
  - **1st Generation Rover Cells (6-8 Ah)**
- Eagle Picher
  - **Baseline 15/20 Ah cells**
  - **1st Generation 50 Ah Cells-Aircraft**
- SAFT
  - **Baseline D cells**
  - **1st Generation Rover Cells (8-9 Ah)**
-

Li-Ion Battery Technology Assessment
Test Plan Outline

- **Electrical Performance Characterization**
  - Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)
  - Range of temperatures (-30, -20, 0, 23, 40°C)
  - Pulse capability (40 and 60A)
  - Impedance measurements
- **Cycle Life Performance**
  - Room temperature cycle life (23° +/- 2°C)
  - Low temperature cycle life (-20°C)
  - High temperature cycling (40°C)
  - Variable temperature cycling
- **Storage Characteristics**
  - 2 Month storage test (0 and 40°C, 50 and 100% SOC)
  - Accelerated storage test: at different SOC (50, 70,100% SOC), temperatures (25, 40, 55°C), and storage conditions.
- **Mission Simulation Testing**

Li-Ion Battery Technology Assessment
Electrical Characterization Studies

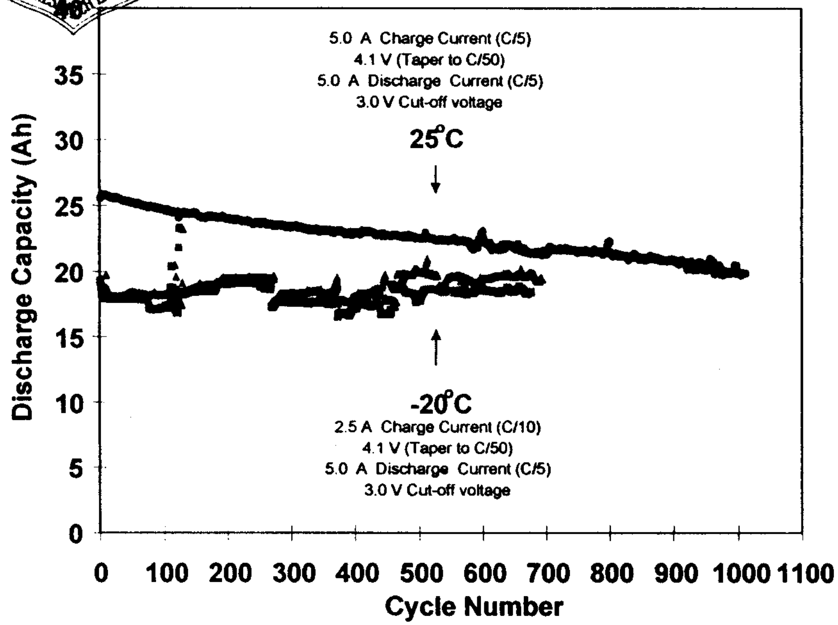


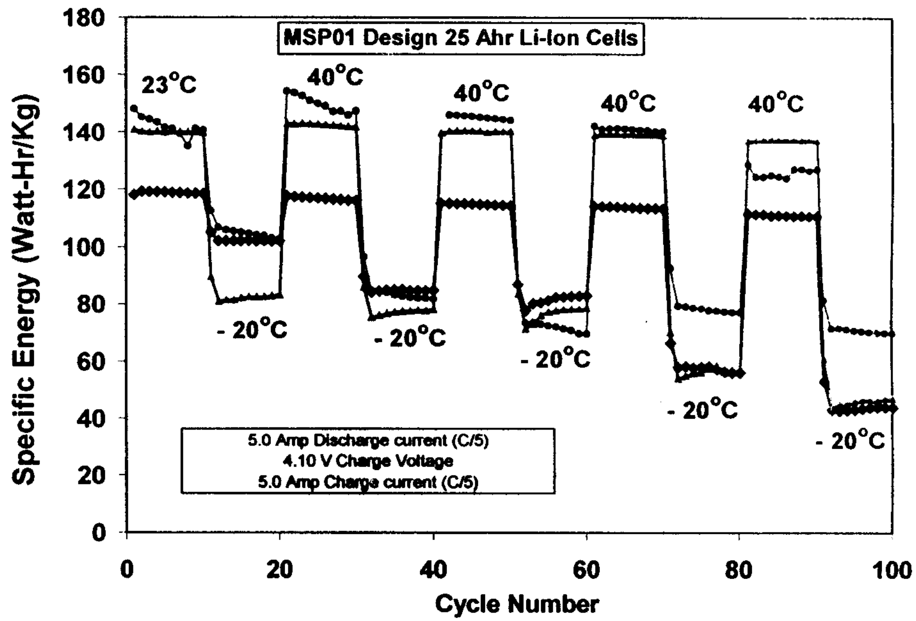


- Cells were found to deliver > 140 Wh/kg at RT.
- Cells were found to deliver about 100 Wh/kg at -20°C.
- Cells can accept charge at -20°C.
- Similar performance capability observed with both 7 and 25 Ah cells.
- Cells from all vendors showed similar capabilities.

Li-Ion Battery Technology Assessment

Cycle Life Studies

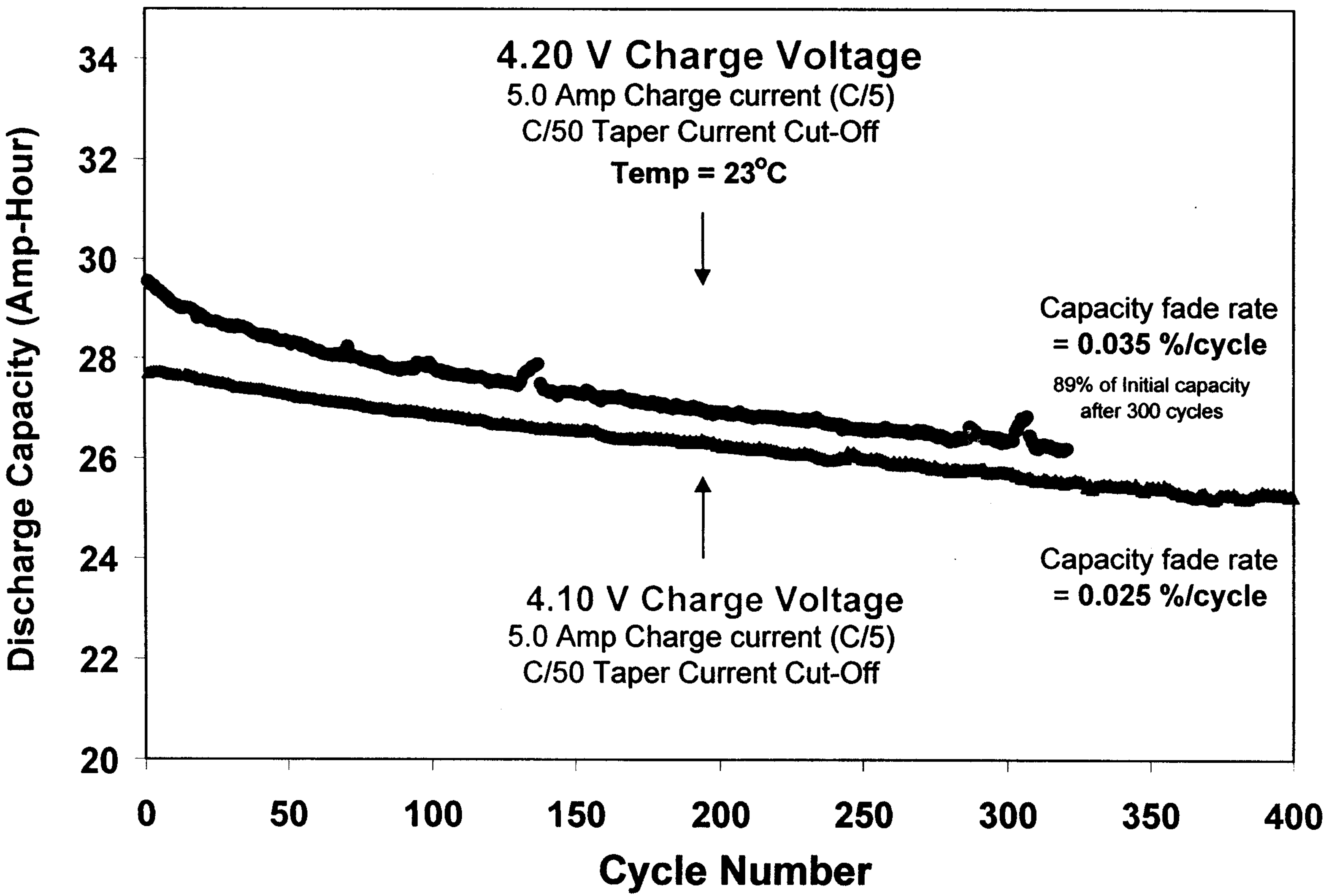




- Cells delivered > 1000 cycles at 100 DOD and RT.
- Cells completed more than 700, 100% DOD cycles at-20°C.
- Observed similar performance capability in both 7 and 25 Ah cells.
- Cells from all vendors showed similar capabilities.
- Cycling cells at alternating low and high temperatures was found effect the low temp performance.

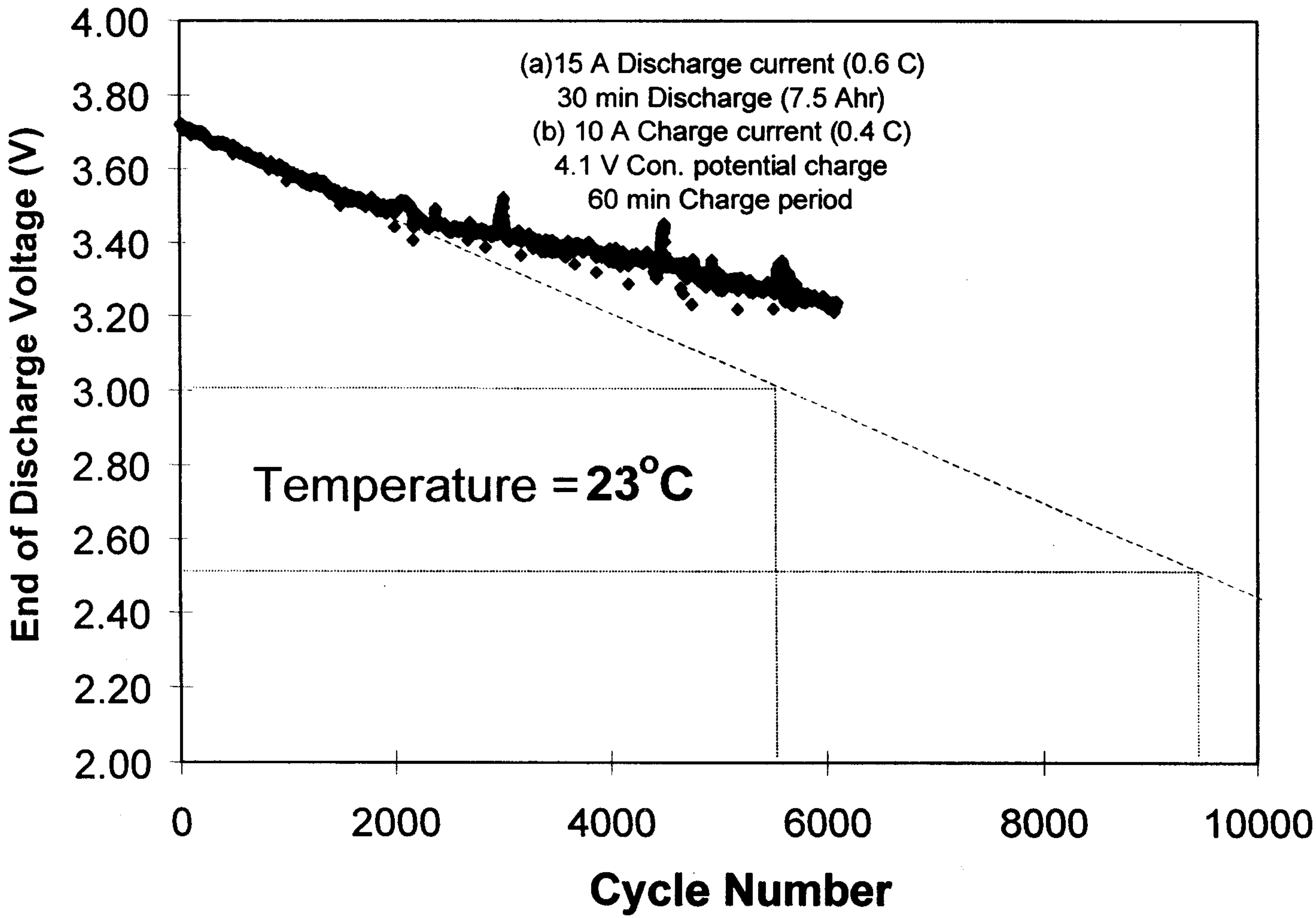
Lithium-Ion Cell Technology Assessment

Effect of Charge Voltage Upon Cycle Life



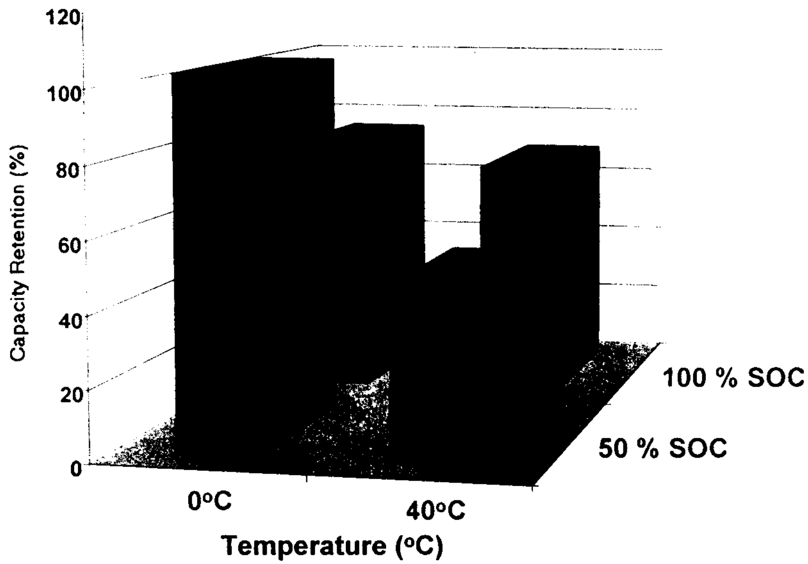
Lithium-Ion Cell Technology Assessment

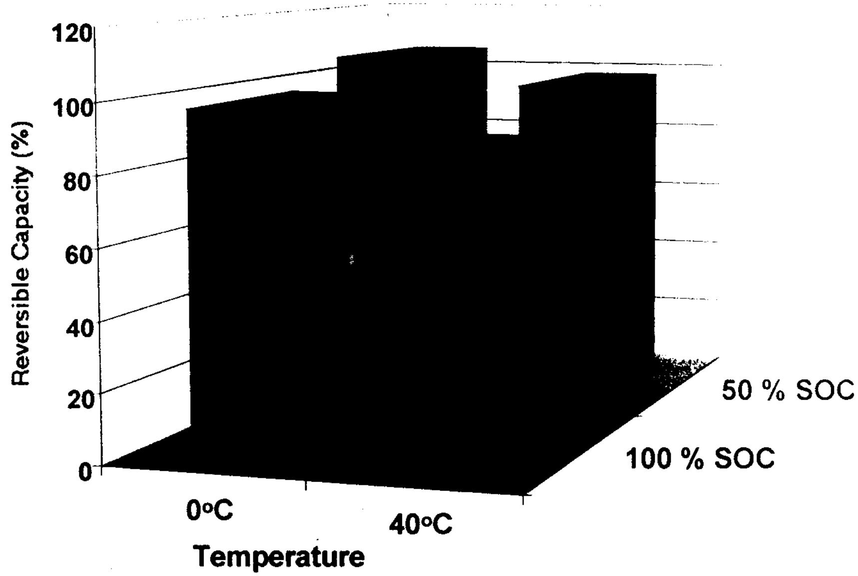
LEO Cycle Life Assessment Studies



Li-Ion Battery Technology Assessment

Effects of Storage Conditions-OCV

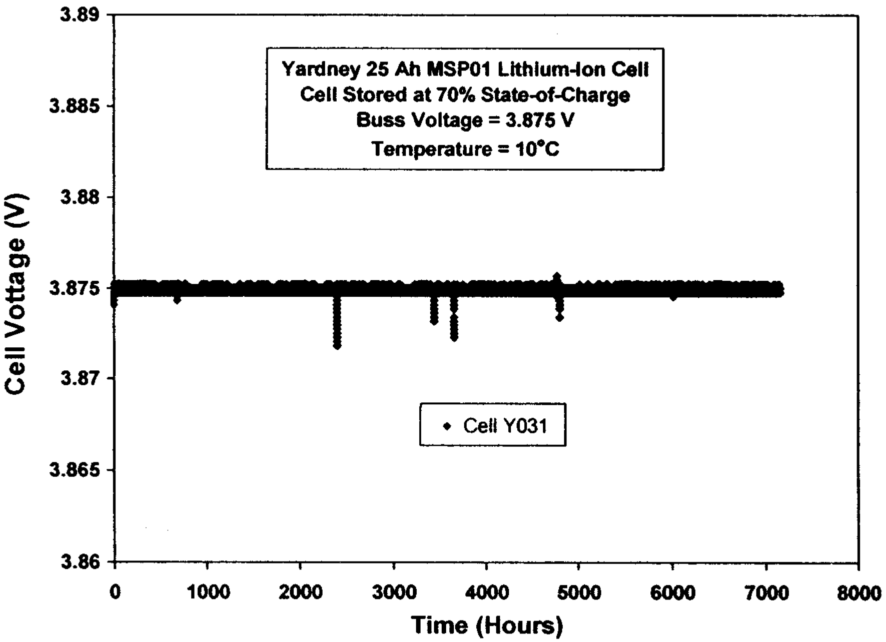


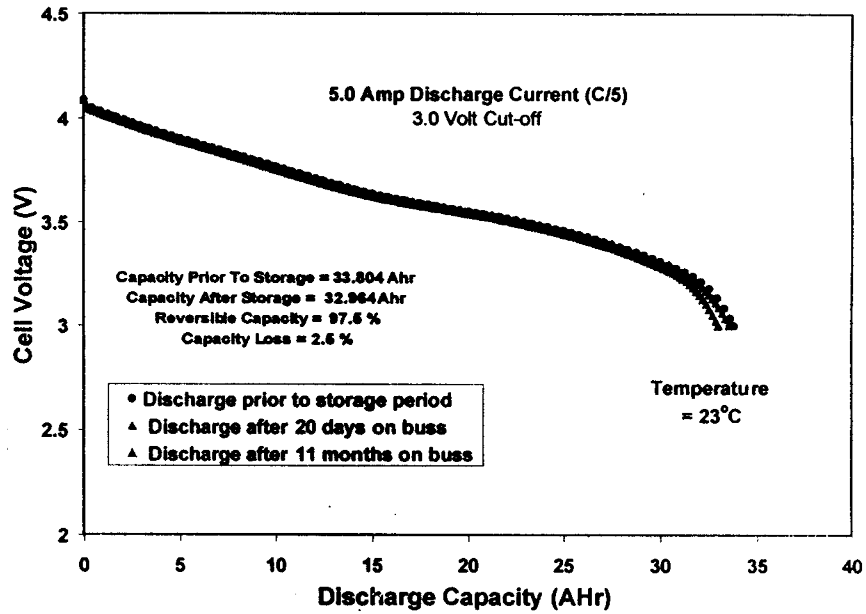


- **Storage of cells at low temperatures was found to minimize self-discharge.**
- **Storage of cells at low temperatures was also found to minimize irreversible capacity losses on storage.**
- **Storage of cells at lower states of charge were found to minimize irreversible capacity losses on storage.**

Li-Ion Battery Technology Assessment

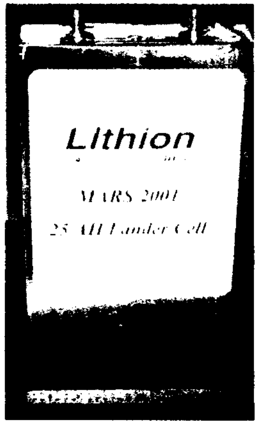
Effects of Storage Conditions-Floating

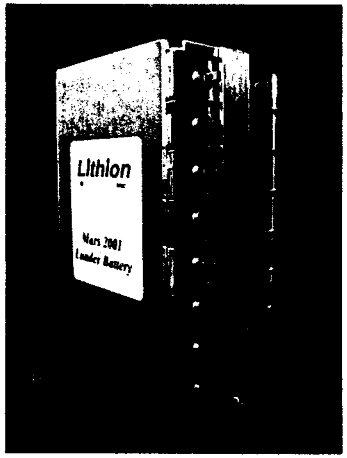


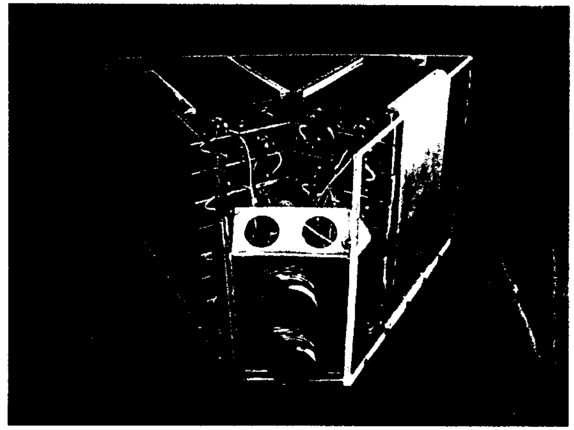


- Cells were stored at 10°C for 11 months on the buss at 3.875V (70% SOC)
- Cells showed similar discharge characteristics to prior storage.

Mars 01 Lander Battery Development Status

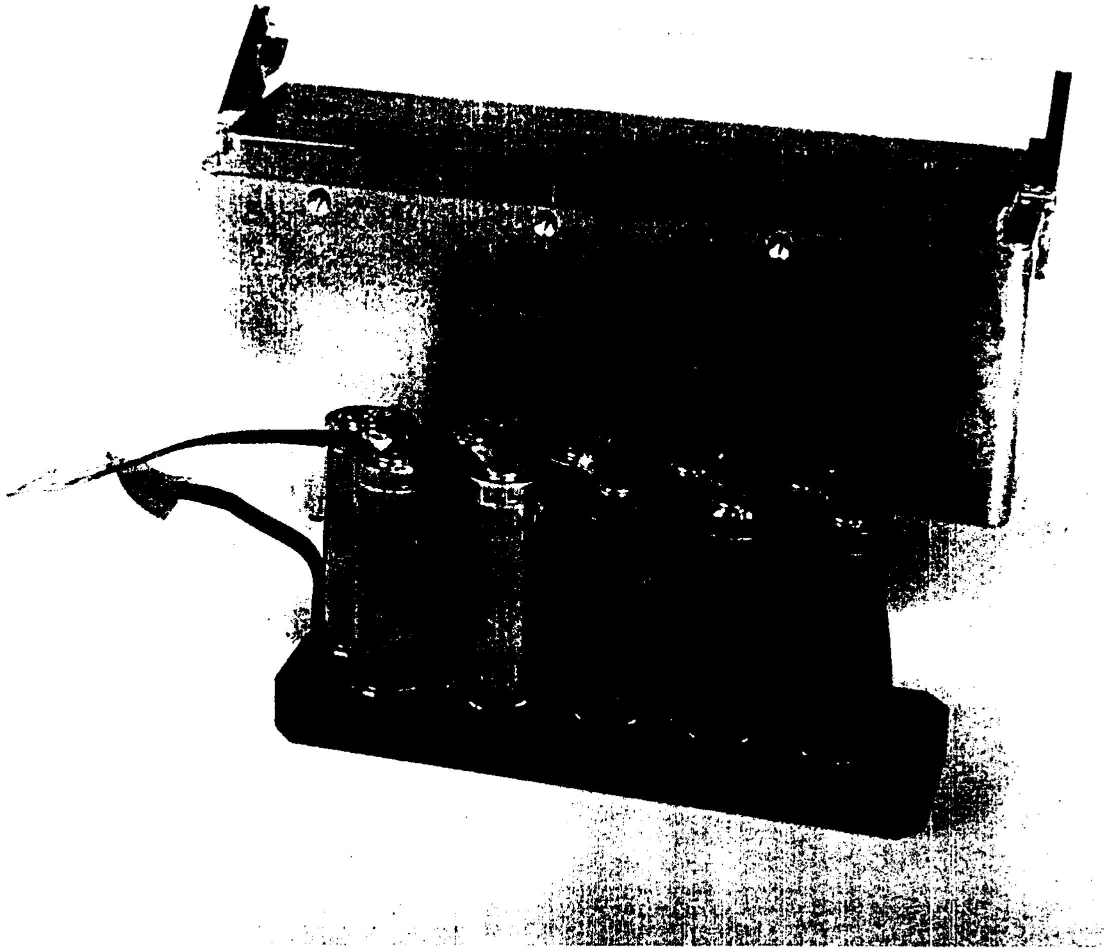






- Ability to withstand launch environments.
- 10 month cruise storage capability
- Mars surface operational capability
  - Met EDL Performance Requirements
  - 50 A Pulse operations at 0°C.
  - 60 simulated Sol operational capability at -20 to 40°C (testing continuing)
- Three year calendar life

Interagency Li-Ion Battery Program
Accomplishments Pistol Rachet Tool Battery



Summary and Conclusions

- NASA and AF have baselined Li-Ion technology for many future planetary missions.
- NASA-DOD have established a joint program to develop aerospace quality Li-Ion batteries for future space missions.
- Yardney, EPI, SAFT, Bluestar continue to develop 7 and 25 Ah cells under a program sponsored jointly by DOD and NASA.
- Successfully demonstrated the readiness of Li-Ion Technology for Mars 01 Lander Mission.
- Technology needs further improvements in the following areas.
    - Cycle Life
    - Long Storage Life
    - Safety and reliability

DOD/NASA Li-Ion Program
Technical Issues

- **Technology is not yet ready for many other NASA/DOD missions missions**
- **Technology needs improvements in several key areas**
  - **Improved low temperature performance (-40°C) -Future Mars Missions, Aircraft**
  - **Ability to cycle between wide temperature extremes-Future Mars Missions, Air craft**
  - **High Pulse power capability-APU, UAV hand held tools, Air Craft**
  - **Very Large Capacity Cells -UAV, APU, GEO**
  - **Long Calendar life (operational & non operational)-GEO and Outer Planets**
  - **Long Cycle Life-LEO and planetary orbiters, Space Station**
  - **Charge management methodology-All missions**
  - **Safety and Reliability- All missions**

Acknowledgements

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